Children's Adaptation to Electropalatography: Evidence From Acoustic Analysis of /t/ and /k/

Kara Brianne Knapp
Brigham Young University - Provo
Children’s Adaptation to Electropalatography: Evidence from

Acoustic Analysis of /t/ and /k/

Kara B. Knapp

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

Shawn L. Nissen, Chair
Ron W. Channell
Kristine Tanner

Department of Communication Disorders
Brigham Young University
June 2014

Copyright © 2014 Kara B. Knapp
All Rights Reserved
ABSTRACT

Children’s Adaptation to Electropalatography: Evidence from Acoustic Analysis of /t/ and /k/

Kara B. Knapp  
Department of Communication Disorders, BYU  
Master of Science

Electropalatography (EPG) is a computer-based device that uses a fitted pseudopalate (similar to an orthodontic retainer) with embedded electrodes to track tongue-to-palate contact during speech for the purposes of providing treatment for a variety of communication disorders. This study evaluated six elementary school-aged children’s ability to adapt their speech to the presence of the pseudopalate in their mouth. The participants’ adaptation for the consonants /t/ and /k/ was examined over eight time intervals throughout a two and a half hour time period. Adaptation was evaluated by measuring the duration, spectral mean, spectral variance, and relative intensity of the target sounds. The participants demonstrated significant changes in speech patterns upon initial placement of the pseudopalate across the spectral parameters of mean, variance, and relative intensity. However, no significant differences in duration were found for either phoneme in the pseudopalate versus no pseudopalate conditions. Therefore, temporal parameters for consonant duration were relatively unaffected by the pseudopalate. The children in the study were able to make some speech adaptations to the pseudopalate, however evidence from the /t/ and /k/ productions indicated that the majority of participants were not able to fully adapt to the EPG device during the two and a half hour time period. Clinicians using EPG must take adaptation effects into consideration.

Keywords: electropalatography, adaptation, stop consonants
ACKNOWLEDGMENTS

I would like to express my thanks to all the people who have supported, encouraged, and motivated me throughout my thesis and masters degree. I would first like to thank Samuel and Barbara Fletcher, who made this research possible. I would also like to express my sincere appreciation to my committee advisors for their support on my thesis. I especially would like to thank my committee chair, Dr. Nissen, for the countless hours and energy he spent advising, editing, and refining my thesis. Lastly, I would like to express my gratitude to my parents. Without their continual support, love, and encouragement throughout my schooling I would never have been able to make it this far, and accomplish all that I have.
# TABLE OF CONTENTS

LIST OF TABLES .......................................................................................................................... v

LIST OF FIGURES ....................................................................................................................... vi

LIST OF APPENDICES ........................................................................................................ viii

DESCRIPTION OF STRUCTURE AND CONTENT ..................................................................... viii

Introduction ................................................................................................................................. 1

Method ........................................................................................................................................ 6

  Participants ............................................................................................................................... 6

  Procedures ............................................................................................................................... 7

Data Analyses ............................................................................................................................ 8

  Measurement Reliability ......................................................................................................... 8

Results ....................................................................................................................................... 9

  Duration ................................................................................................................................. 9

  Spectral Mean ....................................................................................................................... 12

  Spectral Variance .................................................................................................................. 14

  Relative Intensity .................................................................................................................. 16

Discussion .................................................................................................................................. 18

References ................................................................................................................................. 23

Appendix A ............................................................................................................................... 27

Appendix B ................................................................................................................................ 42
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Acoustic Measures (Mean and Standard Deviation) Across Eight</td>
<td>10</td>
</tr>
<tr>
<td>Speaking Conditions for /t/</td>
<td></td>
</tr>
<tr>
<td>2. Acoustic Measures (Mean and Standard Deviation) Across Eight</td>
<td>10</td>
</tr>
<tr>
<td>Speaking Conditions for /k/</td>
<td></td>
</tr>
<tr>
<td>FIGURE</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1.</td>
<td>Duration means for /t/ and /k/ productions across time interval</td>
</tr>
<tr>
<td>2.</td>
<td>Duration for /t/ productions across time interval for each speaker</td>
</tr>
<tr>
<td>3.</td>
<td>Duration for /k/ productions across time interval for each speaker</td>
</tr>
<tr>
<td>4.</td>
<td>Spectral means for /t/ and /k/ productions across time interval</td>
</tr>
<tr>
<td>5.</td>
<td>Spectral mean averages for /t/ productions across time interval for each speaker</td>
</tr>
<tr>
<td>6.</td>
<td>Spectral mean averages for /k/ productions across time interval for each speaker</td>
</tr>
<tr>
<td>7.</td>
<td>Spectral variance means for /t/ and /k/ productions across time interval</td>
</tr>
<tr>
<td>8.</td>
<td>Spectral variance for /t/ productions across time interval for each speaker</td>
</tr>
<tr>
<td>9.</td>
<td>Spectral variance for /k/ productions across time interval for each speaker</td>
</tr>
<tr>
<td>10.</td>
<td>Relative intensity means for /t/ and /k/ productions across time interval</td>
</tr>
<tr>
<td>11.</td>
<td>Relative intensity for /t/ productions across time interval for each speaker</td>
</tr>
<tr>
<td>12.</td>
<td>Relative intensity for /k/ productions across time interval for each speaker</td>
</tr>
</tbody>
</table>
LIST OF APPENDICES

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Annotated Bibliography</td>
<td>27</td>
</tr>
<tr>
<td>B. Informed Consent Documents</td>
<td>42</td>
</tr>
</tbody>
</table>
DESCRIPTION OF STRUCTURE AND CONTENT

This thesis is part of a larger collaborative project, portions of which may be submitted for publication, with the thesis author being one of multiple coauthors. The body of this thesis was written as a manuscript suitable for submission to a peer-reviewed journal in speech-language pathology. An annotated bibliography is presented in Appendix A, and the informed consent documents are included in Appendix B.
Introduction

Electropalatography (EPG), first introduced in 1975 by Fletcher, McCutcheon, and Wolf, is a computer-based device that uses an individually fitted pseudopalate containing 126 electrodes to track and record tongue-to-palate (linguapalatal) contact during speech (Williams, 2009). Considering that EPG can be used to provide real-time visual biofeedback of where the tongue is contacting the palate during the production of specific sounds during speech, the device has been used for a number of years to treat a range of communication disorders. It has been used in the treatment of articulation and phonological disorders (Dagenais, 1995; Gibbon & Paterson, 2006), as well as other disorders such as dysarthria secondary to traumatic brain injury (Kuruvilla, Murdoch, & Goozee, 2008), apraxic speech (Southwood, Dagenais, Sutphin, & Garcia, 2004), and disordered swallowing (Horn, Kuhnast, Axmann-Krcmar, & Goz, 2004).

One possible drawback to the use of EPG in treating communication disorders is that the device requires a custom-made, 2 mm thick, acrylic artificial palate, similar to an orthodontic retainer, to be placed inside the speaker’s mouth with wires extending from the pseudopalate to a small external processing unit. The obstruction, or perturbation, in the oral cavity caused by the pseudopalate and the connecting wires can cause individual sounds to become acoustically distorted if speakers are unable to adapt their speech motor patterns to the presence of the EPG device. Previous studies have examined adaptation to the EPG device by adults, however, there has been very little published research on the ability of children, who are in the process of developing their motor speech abilities, to adapt their speech to the presence of a pseudopalate (Dean, 2008; McAuliffe, Robb, & Murdoch, 2007; Williams, 2009).

Research with adult speakers has indicated that individuals are generally able to adapt their speech motor patterns in response to a number of different perturbations in the oral cavity
such as bite blocks, lingual pellets, magnets, dental prostheses, and artificial pseudopalates. Research has shown that adults are able to adapt their speech motor patterns to the presence of a bite block in a relatively rapid manner. A bite block is an intraoral device made out of rubber or styrofoam to fixate the jaw and is used in studies to make measurements on the way that individuals adjust their lip and tongue movements during speech when there is an obstruction in the mouth. Fowler and Turvey (1980) found that speakers were able to make immediate compensations in their speech to the presence of the bite block and that both the latency and quality of the vowels spoken did not differ significantly from those spoken under typical conditions. Speakers are often able to adapt their vowel productions to a bite block by exaggerating the shapes of their tongue and lips (Gay, Lindblom, & Lubker, 1981). In contrast to the findings of Fowler and Turvey (1980), research by Flege, Fletcher, and Homiedan (1988) indicated that while speakers showed some immediate speech adaptation to a bite block, their adaptation to the obstruction was often incomplete for vowels and consonants. However, Flege et al. (1988) did find that 10-minutes of practice resulted in a significant increase of speech intelligibility. Likewise, McFarland and Baum (1995) did not find immediate adaptation in speaker’s vowel productions, but did note significant improvement after a 15-minute practice period, with only a limited degree of adaptation for obstruent sound productions.

Previous research has also reported that adult speakers are able to partially adapt their speech to the physical perturbation caused by lingual pellets and magnets. Weismer and Bunton (1999) indicated that a group of listeners were unable to make reliable identifications of when a speaker had the lingual pellets on or off. The authors concluded that although the adult speakers did not completely adapt to the presence of lingual pellets, there was only minimal effect on global speech timing. Another study, performed by Weaver (2005), assessed the effects that
small lingual magnets have on the production of the American English fricatives /s/ and /ʃ/, as well as individuals rate of adaptation to these structural impediments in their mouth. Weaver found that the presence of a lingual magnet initially created a significant disturbance in terms of spectral mean and variance of the production of /ʃ/ in the final position of words. Although there was significant disturbance to the /ʃ/ initially, speakers were able to adapt to the presence of the magnet after only five minutes of conversation.

Researchers have also studied the ability of adults to adapt their speech motor patterns to the presence of a dental retainers or prostheses. Hamlet and Stone (1982) found that although most adult speakers exhibited some adaptation over the course of a week, only seven out of thirteen participants were able to fully adapt to a dental prosthesis over a one-week time period. Hamlet, Cullison, and Stone (1979) found that individuals’ attempts to adapt their speech to a dental prosthesis often resulted in an increase in fricative duration. On average speakers were found to produce /s/ productions 17 ms longer. However, despite these increases in fricative duration, the researchers reported that adult speakers generally adapted to the prosthesis in a relatively rapid manner.

Orthodontic retainers are often thought to be very similar in structure to the EPG pseudopalate, however the two appliances have two primary differences. The EPG pseudopalate is often thicker than an orthodontic retainer, due primarily to the embedded electrodes. In addition, the EPG device has wires that protrude from the front of the pseudopalate and extend out of the mouth, which may impede lip movement. Due to the physical differences between the two devices, findings concerning adaptation to an orthodontic retainer do not fully explain how speakers adapt to an EPG device.
A number of studies have examined how individuals adapt their speech motor patterns when an artificial pseudopalate has been placed in their mouth (e.g., Aasland, Baum, & McFarland, 2006; McAuliffe et al., 2007; Searl, Evitts, & Davis, 2006), the findings of which have been found to be variable across adaptation time. Dean (2008) and Williams (2009) found from their study looking at adaptation over a 20 minute time period that individuals were unable to make complete adaptations to the pseudopalate with stops and fricatives. Searl et al. (2006) found that speakers initially had slightly distorted consonants upon insertion of the pseudopalate, however, they returned to normal within 30 minutes of wearing the EPG device. McAuliffe et al. (2007) found that the majority of participants were able to adapt to the EPG device over a period of 45 minutes. However, McLeod and Searl (2006) found that speakers took a much longer period of time to fully adapt to the EPG device. Their results indicated that that individuals were able to adapt their speech to near normal within two hours, and that the effect of the pseudopalate only continued to decrease over time.

Research has also found that the amount of time it takes for an individual to adapt to a pseudopalate is contingent on the types of sounds being produced. A study evaluating the perceptual parameters of vowels /i, a, u/ through identification ratings from 10 naïve listeners, found that these vowels exhibited no significant differences between the palate and normal conditions. In contrast the fricatives /s, ñ/ have been found to be significantly affected by the presence of a pseudopalate requiring a greater period of time in order for adaptation to take place. This same study found that along with vowels, stops /p, t, k/ were not significantly affected (Baum, McFarland, & Diab, 1996). Conversely, perceptual analysis studies done by Williams (2009) show that 20 minutes of adaptation to a pseudopalate resulted in stop-loaded sentences that were given consistently poorer ratings than fricative-loaded sentences.
Previous research suggests that a high degree of variability exists in how individual speakers are affected by and adapt to an EPG pseudopalate (Baum & McFarland, 2000; McAuliffe et al., 2007). Baum and McFarland (2000) examined the adaptation patterns of three speakers and discovered a significant amount of variability from speaker to speaker after one hour of wearing the pseudopalate. One speaker in the study showed the ability to adapt their speech to the presence of the pseudopalate through the acoustic analysis that was performed; however, this same individual did not show the same adaptive speech patterns within the perceptual analysis. Likewise, another speaker showed adaptation within only the perceptual analysis performed and showed no significant adaptation within the acoustic analysis. Moreover, one speaker demonstrated essentially no effects to the existence of a pseudopalate placed in the oral cavity.

Although research with adults may provide insight into how children might adapt to an EPG pseudopalate, it is unclear if most young speakers are able to adapt in a similar method or in the same time frame. In part because children’s speech differs from adults in two fundamental ways: their palates are anatomically much smaller, and they are still fine-tuning their speech motor control (Cheng, Murdoch, Goozée, & Scott, 2007; Fox & Nissen, 2005; Nittrouer, 1995). Regardless of whether the pseudopalate has been made for an adult or a child, often the size of the pseudopalate remains the same. This causes a larger relative obstruction in the smaller oral cavity of a child as compared to an adult. Cheng et al. (2007), advised, “It is possible that with a smaller oral cavity, children may be more susceptible to the effects of palatal perturbation…

Clinicians should be alert to the possible articulatory changes that occur when a pseudopalate is in place, particularly when interpreting EPG data from young children” (p. 386). In addition to their palate being anatomically smaller, children’s speech productions are often still undergoing
development and refinement well into adolescence, especially for later-developing sounds such as affricates and fricatives (Nissen & Fox, 2005; Nittrouer, 1995). Some studies suggest that speech motor control in children doesn’t even fully develop until sometimes as old as 17 years of age because of the anatomical and developmental changes taking place (e.g., Cheng et al., 2007).

Considering that the device is often used to treat speech sound disorders, additional research with school-aged children is needed. According to a survey of speech therapists in Scotland, out of 60 children receiving therapy using the EPG device, 52% of them were between six and ten years old (Gibbon & Paterson, 2006). A study performed by Dagenais (1995) assessing candidacy for EPG treatment found that suitable candidates were often school-aged children older than seven years of age. Thus the current study was designed to evaluate adaptation to an EPG pseudopalate in school-aged children and compare these findings to studies performed looking at adaptation with adults. Specifically this study examined the ability of six children (ages of 7;0 - 9;11 years) to adapt their stop consonant productions over a two and a half hour time period, as measured by a number of acoustic characteristics.

**Method**

This thesis describes one portion of a more comprehensive project on speech adaptation, thus the methodology described below is similar to that used in other parts of the project. In addition, to allow for subsequent comparison of these results to previous research involving adults, this study is a partial replication of methods used in previous research (Dean, 2008; McAuliffe et al., 2007; Williams, 2009).

**Participants**

Six elementary school-aged children (three male and three female) were recruited from the local community to participate in the study. The children were between the ages of 7;0-9;11
years ($M = 8.3$) and had typical developing dentition and normal hearing acuity. All participants had their hearing screened with pure-tone air conduction thresholds of 25 dB HL at octave frequencies from 500 to 8000 Hz before they participated in data collection. The children were all native speakers of American English, with no history of wearing an orthodontic retainer or of being diagnosed with a speech, language, or neuromotor disorder. Each child’s guardian read and signed an informed consent document. Prior to the collection of any data, the methodology of this study was approved by the Brigham Young University Institutional Review Board for Human Subjects Research.

**Procedures**

Each speaker had a dental impression made by a local orthodontic technician prior to the beginning of data collection. After the impression had been made, the technician made a plaster stone model from which a 2 mm thick pseudopalate with the embedded circuits was produced by Complete Speech®. Each participant was asked to use mouthwash and brush his or her teeth before placing the pseudopalate in the mouth to reduce any interference with the pseudopalate.

Each speaker’s adaptation to wearing the EPG pseudopalate was assessed throughout one session lasting roughly two and a half hours. Acoustic data were gathered at the following eight intervals: (a) prior to pseudopalate placement, (b) immediately following pseudopalate placement, (c) 30 minutes following pseudopalate placement, (d) one hour following pseudopalate placement, (e) one hour and 30 minutes following pseudopalate placement, (f) two hours following pseudopalate placement, (g) immediately following pseudopalate removal, and (h) 30 minutes following removal of the pseudopalate. Participants repeated six CVC words (*teeth, taught, tooth, keep, cop, coop*), three times each, in random order in the carrier phrase *say _____ again* during each of the eight data collection intervals. The six target words were
comprised of a voiceless stop consonant (/t/ or /k/) in the initial position followed by a monophthongal vowel (/i/, /a/, or /u/). Furthermore, a one-minute conversation with the participant was recorded but this data was not included as part of the analysis.

Participants were instructed to interact in play with other participants of similar age who were also wearing the pseudopalate to facilitate adaptation to the pseudopalate after placement. Speech recordings were collected using a high-quality low impedance dynamic microphone and preamplifier. All acoustic recordings were sampled at a rate of 44.1 kHz with a quantization of 16 bits. Custom-designed computer programs (MATLAB) were used to elicit, record, and acoustically analyze the stimuli.

Data Analyses

A waveform display, assisted by spectrographic inspection using Adobe Audition, was used for segmentation of the onset and offset of the target sounds. In addition, 10% of all tokens were independently analyzed by a second person and later correlated to the original segmentation of these same tokens to test for segmentation accuracy and reliability. All speech samples were high-pass filtered with a cutoff frequency of 70 Hz. Using spectral moment analysis, the stop consonant productions were described in terms of spectral mean, spectral variance, spectral skewness, and spectral kurtosis, following the computational algorithms outlined in previous studies (Jongman, Wayland, & Wong, 2000; Nissen & Fox, 2005, 2009).

Measurement Reliability

To test for segmentation accuracy and reliability, 10% of all tokens were independently analyzed by a second person and subsequently correlated with the original segmentation of these same tokens. Using both sets of segmentation points, the acoustic measures were recalculated and Pearson correlations on these two sets of data were compared in terms of duration (mean
absolute difference = 2.27 ms; $r = .99$, $p < .0001$), spectral mean (mean absolute difference = 79.62 Hz; $r = .97$, $p < .0001$), spectral variance (mean absolute difference = 0.27 MHz; $r = .98$, $p < .0001$), and relative intensity (mean absolute difference = .09 dB; $r = .99$, $p < .0001$).

Results

Descriptive statistics for the dependent variables of duration, spectral mean, spectral variance, and intensity were calculated for the stop productions (/t/ and /k/) across eight time intervals and tables below. Mean and standard deviation values for the spectral and acoustic measures for /t/ and /k/ productions across time intervals can be found in Tables 1 and 2, respectively.

Duration

The overall mean duration values for /t/ and /k/ productions across the eight time intervals are shown in Figure 1 below. When the data were collapsed across all six speakers, the impact of the pseudopalate on the speaker’s productions was minimal. There was an increase in duration for /k/ productions at the +120 minute time interval, which was primarily due to the relatively high duration values from one speaker (F2) during that time interval. This increase in duration was quickly followed by a decrease in duration upon removal of the pseudopalate. Figures 2 and 3 display the duration measures for /t/ and /k/ across the eight time periods for each individual male and female speaker. For all of the participants the impact of the pseudopalate on the duration of the /t/ and /k/ productions was relatively minimal, thus the amount of subsequent adaptation was also limited in scope.
Table 1

*Acoustic Measures (Mean and Standard Deviation) Across Eight Speaking Conditions for /t/**

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Duration(^a)</th>
<th>Spectral Mean(^b)</th>
<th>Spectral Variance(^c)</th>
<th>RMS(^d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(M)</td>
<td>(SD)</td>
<td>(M)</td>
<td>(SD)</td>
</tr>
<tr>
<td>Pre</td>
<td>98</td>
<td>31</td>
<td>5327</td>
<td>628</td>
</tr>
<tr>
<td>0</td>
<td>102</td>
<td>35</td>
<td>3866</td>
<td>369</td>
</tr>
<tr>
<td>30</td>
<td>106</td>
<td>28</td>
<td>4402</td>
<td>408</td>
</tr>
<tr>
<td>60</td>
<td>91</td>
<td>25</td>
<td>4424</td>
<td>518</td>
</tr>
<tr>
<td>90</td>
<td>89</td>
<td>24</td>
<td>4837</td>
<td>564</td>
</tr>
<tr>
<td>120</td>
<td>97</td>
<td>31</td>
<td>4725</td>
<td>416</td>
</tr>
<tr>
<td>Post</td>
<td>99</td>
<td>38</td>
<td>5297</td>
<td>462</td>
</tr>
<tr>
<td>Post 30</td>
<td>89</td>
<td>37</td>
<td>5572</td>
<td>574</td>
</tr>
</tbody>
</table>

Note. \(^a\)Values reported in milliseconds. \(^b\)Values reported in hertz. \(^c\)Values reported in megahertz. \(^d\)Values reported in root mean square in decibels.

Table 2

*Acoustic Measures (Mean and Standard Deviation) Across Eight Speaking Conditions for /k/**

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Duration(^a)</th>
<th>Spectral Mean(^b)</th>
<th>Spectral Variance(^c)</th>
<th>RMS(^d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(M)</td>
<td>(SD)</td>
<td>(M)</td>
<td>(SD)</td>
</tr>
<tr>
<td>Pre</td>
<td>108</td>
<td>35</td>
<td>3504</td>
<td>322</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>29</td>
<td>3720</td>
<td>549</td>
</tr>
<tr>
<td>30</td>
<td>107</td>
<td>26</td>
<td>3542</td>
<td>373</td>
</tr>
<tr>
<td>60</td>
<td>92</td>
<td>20</td>
<td>3798</td>
<td>434</td>
</tr>
<tr>
<td>90</td>
<td>93</td>
<td>22</td>
<td>3868</td>
<td>382</td>
</tr>
<tr>
<td>120</td>
<td>125</td>
<td>88</td>
<td>3352</td>
<td>329</td>
</tr>
<tr>
<td>Post</td>
<td>107</td>
<td>37</td>
<td>4096</td>
<td>429</td>
</tr>
<tr>
<td>Post 30</td>
<td>95</td>
<td>30</td>
<td>3738</td>
<td>349</td>
</tr>
</tbody>
</table>

Note. \(^a\)Values reported in milliseconds. \(^b\)Values reported in hertz. \(^c\)Values reported in megahertz. \(^d\)Values reported in root mean square in decibels.
Figure 1. Duration means for /t/ and /k/ productions across time interval.

Figure 2. Duration for /t/ productions across time interval for each speaker.
**Figure 3.** Duration for /k/ productions across time interval for each speaker.

**Spectral Mean**

The overall spectral mean values for /t/ and /k/ productions across the eight time intervals are shown in Figure 4 below. As shown in this figure, for the group of speakers there was a notable impact on /t/ productions after placement of the pseudopalate, followed by a gradual increase in spectral mean. However, there were minimal changes in spectral mean for the /k/.

Figures 5 and 6 display the spectral mean measures for /t/ and /k/ across the eight time periods for each individual male and female speaker. As shown in Figure 5, all six participants in the study demonstrated a decrease in spectral mean immediately following placement of the pseudopalate. Over the two hour adaptation period each of the six participants demonstrated a varied, yet gradual increase toward the pre-placement levels in the spectral mean for their /t/ productions.
**Figure 4.** Spectral means for /t/ and /k/ productions across time interval.

**Figure 5.** Spectral mean averages for /t/ productions across time interval for each speaker.
Participant M2 demonstrated a subsequent decrease in spectral mean following two hours of wearing the pseudopalate. As illustrated in Figure 6, the spectral mean of five of the six participant’s /k/ productions were affected by the placement of the pseudopalate. The degree of adaptation for the spectral mean of the /k/ productions was highly variable across participants.

**Spectral Variance**

The overall mean spectral variance values for /t/ and /k/ productions across the eight time intervals are shown in Figure 7 below. In Figure 7, for both /t/ and /k/ the mean spectral variance values are impacted by the presence of the pseudopalate. The analysis indicates an overall increase in spectral variance for /t/ and a decrease for /k/. Figures 8 and 9 display the spectral variance measures for /t/ and /k/ across the eight time periods for each individual speaker.
Figure 7. Spectral variance means for /t/ and /k/ productions across time interval.

Figure 8. Spectral variance for /t/ productions across time interval for each speaker.
As shown in Figure 8, for the majority of participants the spectral variance of /t/ productions increased after the placement of the pseudopalate, followed by only minimal adaptation. As illustrated in Figure 9, the initial impact of the pseudopalate and their subsequent adaptation varied across the speakers. Three speakers showed an increase in spectral variance for /k/ immediately following placement of the pseudopalate, whereas the remaining three speakers showed a decrease following initial placement of the pseudopalate. The degree of adaptation to the device also varied across the individual participants.

Relative Intensity

The mean relative intensity values across the eight time intervals are shown in Figure 10 below. Minimal overall changes in the relative intensity for the /k/ were found. In contrast, the mean relative intensity of /t/ demonstrated a sizeable increase after pseudopalate placement and followed by a gradual decrease throughout the two hour adaptation period. Figures 11 and 12
Figure 10. Relative intensity means for /t/ and /k/ across time interval.

Figure 11. Relative intensity for /t/ productions across time interval for each speaker.
Figure 12. Relative intensity for /k/ productions across time interval for each speaker.

display the relative intensity measures for /t/ and /k/ across the eight time periods for each individual speaker. In Figure 11, all six participants showed a decrease in relative intensity for the /t/ productions after initial placement of the pseudopalate, followed by a minimal increase over the 2 hour adaptation period. The impact of the pseudopalate on the duration of the /k/ productions was relatively minimal, thus the amount of subsequent adaptation was also limited in scope, as shown in Figure 12.

Discussion

The current study evaluated children’s speech adaptation to an EPG pseudopalate over a period of two hours and a half hours while producing words containing the stop consonants /t/ and /k/. The impact of the pseudopalate on the participants’ speech and their patterns of adaptation varied depending on the acoustic measure.
For the acoustic measure of duration, the productions of all six speakers were found to only be minimally impacted by the presence of the EPG device, either as a group of speakers or individually. The spectral mean values for /t/ decreased immediately following placement of the device; however, the impact of the presence of the device on /k/ was relatively minor. In terms of spectral mean, all of the participants had partially or fully adapted their /t/ productions to pre-placement levels. For two participants near complete adaptation occurred after 30 minutes of practice with the pseudopalate in place. Although the pattern of impact of the device on the spectral variance measures was highly variable speakers, nonetheless, generally speakers exhibited an immediate increase in spectral variance for /t/ and a decrease for /k/ following placement. Although the patterns of initial impact from the pseudopalate differed across participants, the majority of speakers adapted their production at least partially toward baseline levels. The placement of the device had an immediate impact on the relative intensity of the /t/ productions, but a relatively minor affect on the /k/ productions. After speaking with the pseudopalate in place for two hours, three of the participants adapted their productions to near baseline levels, two participants partially adapted their speech, and one participant showed relatively little to no adaptation.

The results of the present study demonstrated both similarities and differences to previous research on speech adaptation to the EPG pseudopalate in adult speakers (Dean, 2008; McAuliffe et al., 2007; Williams, 2009). Similar to the findings of the current study, Dean (2008) also found a decrease in the spectral mean of /t/ immediately after placing the pseudopalate in the participant’s mouth. However, Dean found this significant decrease in spectral mean for both /t/ and /k/, whereas the current study observed this decrease with only /t/ productions. Similar to the current study Dean (2008) and Williams (2009) found that some speakers adapted their obstruct
productions after a relatively short amount of time (20 minutes), however across a number of acoustic and perceptual measures the majority of speakers did not fully adapt their speech after 20 minutes of practice with the pseudopalate in place. These authors concluded that 20-minutes was an insufficient amount of time for speakers to adapt to the pseudopalate. McAuliffe et al. (2007) found while evaluating adaptation over a three hour time interval that, “the magnitude of imprecision [imprecision of articulation caused by insertion of the pseudopalate] was found to return to normal following 45-minutes to 3-hours of adaptation” (pg. 893). However unlike the work of McAuliffe et al., the current study found that for most of the acoustic parameters measured the majority of child participants did not fully adapt their speech to the presence of the EPG device after two hours of practice. Similar to the work of McAuliffe et al. with adult speakers, the current study also found that the consonant durations were relatively unaffected by the presence of the pseudopalate.

There may be a number of reasons for the differences seen between the ability of children and adults to adapt their speech to the presence of an EPG pseudopalate. One reason for the differences may be the relatively high degree of variability in the speech patterns of typical developing children when compared to adults. Cheng et al. (2007) observed that younger speakers (6 to 11 year olds) had more tongue-to-palate contact and less lingual control than adolescent and adult speakers. A study performed by Nittrouer (1995) found that children learn separate aspects of speech production at different rates. The results of the present study show that some children’s articulatory gestures achieved adult-like precision at a later stage of development.

Additionally, the initial impact and subsequent adaptation to the pseudopalate may be related to the size of the device relative to the size of the speaker’s oral cavity. For the Complete
Speech© system used in this study, the same size of pseudopalate is used for both children and adult speakers. Thus the device creates a larger relative obstruction for younger speakers that typically have a smaller oral cavity, which may make speech adaptation to the device more difficult for children.

The speaker’s stage of cognitive development may also be a contributing factor to the differences in adaptation between children and adults. Adults may be able to develop strategies that will enable them to adapt their speech to the pseudopalate more quickly and effectively than children, especially considering that children are still fine-tuning and stabilizing many speech motor patterns (Nissen & Fox, 2009).

One of the limitations to this study was that the acoustic parameters measured were analyzed only in isolation. Future research that examines a combination of acoustic cues may provide additional information on children’s ability to adapt their speech to the EPG device. One of the most naturalistic and effective ways to evaluate a combination of acoustic characteristics is by conducting a perceptual study using listener ratings. Another limitation to the current study may have been the limited number of participants. Although the general trends of the acoustic data could be examined descriptively, recordings from additional speakers would have allowed the use of inferential statistics and the ability to more effectively generalize findings to the population at large.

Considering that it may have been difficult for young children to attend to the experimental task throughout the hour adaptation period, speaker fatigue may also have influenced the data. Although some fatigue is to be expected due to children being unaccustomed to wearing a pseudopalate in their mouth, it may be beneficial to use a smaller number of stimuli and data collection time intervals in future studies.
Considering the increased use of EPG in treating children with speech sound disorders, a greater understanding of how children adapt to an EPG pseudopalate is needed. Findings from this study found that for children the placement of a pseudopalate often results in a disturbance in the acoustic and spectral characteristics of productions of the stop phonemes /t/ and /k/.

Examination of the children’s speech over a two-hour period of time revealed that some of the speakers were able to partially or fully adapt their productions to the presence of the device. However the children’s adaptation, in terms of some of the measured acoustic characteristics, was highly variable both in degree and manner. It is unclear whether more time practicing with the pseudopalate would allow for more complete adaptation to occur, or even if these differences are perceptually relevant. Despite the limitations of this study, the findings of this study provide insight into the acoustic nature of children’s speech adaptation and help inform the methodology of future research in the use of EPG technology to treat speech sound disorders in children.
References


Appendix A

Annotated Bibliography


*Objective:* The purpose of this study was to examine speech adaptation to an EPG device when producing the /s/ phoneme. *Methods:* Nine young adults, ages 19-27 years, participated in the study. Two custom-made EPG devices, one thin (1mm) and one thick (6mm), were made for each participant. Speakers were asked to produce the nonsense syllable /asa/ 10 times with no pseudopalate in place, with the thin pseudopalate in place, and also with the thick pseudopalate in place. Word productions were elicited every 15-minutes during a one-hour period of time, in between which the speakers were required to produce multiple /s/-laden sentences with the thick pseudopalate in place. At the end of the one-hour time period, data were collected from the speakers with no pseudopalate in place. Speech productions across the different speaking conditions were evaluated in terms of fricative duration and centroid frequency. A perceptual analysis using 10 listeners was also performed. *Results:* Frication duration measures were found to be much longer at the 60-minute time interval than at any other time interval. The centroid frequencies from /s/ productions for both types of pseudopalates were substantially lower than in the no pseudopalate condition. However, 15-minutes of practice with the thick pseudopalate caused the centroid frequencies to increase to near baseline levels for the rest of the hour. Listener ratings for speech produced with the thin pseudopalate in place were significantly higher than for the thick pseudopalate immediately following placement of the device. *Conclusions:* Participants demonstrated more disturbances in speech quality when the thick pseudopalate was in place compared to the thinner device, and required a longer adaptation period to adjust to the presence of the pseudopalate.
Objective: The purpose of this study was to examine adaptation to an oral obstruction placed in the mouth while producing the fricative /s/. The study also assessed how the vowel environment influences participant’s adaptation to the device. Method: Four adult French speakers participated in the study. Speech production of the fricative /s/ was assessed at three different time intervals: (a) immediately after insertion of the pseudopalate, (b) one hour following intensive practice with the /s/ phoneme in the syllables /si/, /sa/, and /su/ with the pseudopalate in place, and (c) one hour after removal of the pseudopalate. Intensive practice and adaptation to the device included having the speakers produce passages loaded with the /s/ phoneme. The participant’s ability to adapt to the device was measured in terms of both acoustic and perceptual analyses. Results: Time interval, palatal condition, and vowel ANOVAs on the perception test for each speaker were computed and averaged across all ten repetitions. For speaker 1, no significant results were found. Productions for speaker 2 had lower perceptual ratings after insertion of the pseudopalate in contrast to the no-pseudopalate condition for all syllables excluding /sa/. The productions of speaker 3 showed significantly lower ratings for the /su/ phoneme in the pseudopalate condition (becoming worse over time); however, /si/ ratings were found to be surprisingly higher in the pseudopalate condition. Conclusion: Patterns of speech adaptation varies across individual speakers even with intensive practice targeting specific phonemes.


Objective: The purpose of this study was to examine adaptation to two artificial palates of different thicknesses. Method: Fifteen female adult French speakers produced five repetitions of each stimulus immediately following placement of the EPG device and again after 15 minutes of speech. The experimental stimuli included a series of vowels /i, a, u/, voiceless stop consonants /p, t, k/, and voiceless fricatives /s, sh/ produced in isolation and a CV context. The intelligibility of the speech productions was evaluated
through acoustic analysis and perceptually rated by 10 listeners. **Results:** The acoustic analysis indicated no significant changes to vowel and consonant productions; however, significant changes were observed with fricatives under perturbation. The perceptual analysis revealed that listeners were better at accurately identifying vowels than consonants, with fricatives having the lowest identification accuracy. **Conclusion:** Adaptation to the pseudopalate occurred quickly for vowels but full adaptation did not occur for fricatives.


**Objective:** The purpose of this study was to examine the development of tongue-to-palate contact during speech. **Method:** The researchers collected data from 48 children and adults. All participants were fitted with a 1.5-2 mm thick artificial palate. Before assessment, each speaker went through a 20-minute desensitization period to become accustomed to the pseudopalate. Speakers were asked to repeat six words of CV and CVC construction in short sentences five times each. The speech productions were examined in terms of the pattern of tongue-to-palate contact and the variability of contact. **Results:** Results indicated that younger speakers (6 to 11 year olds) had more palatal contact than adolescent and adult speakers. Statistically, the amount of linguapalatal contact decreased linearly with age for both the /l/ and /t/ phonemes. **Conclusion:** The researchers concluded that younger speakers exhibit a higher amount of tongue-palate contact and less lingual control during speech than adolescent and adult speakers.


**Objective:** This study reviewed effective treatment methods for articulation and phonological disorders using EPG. The author discussed candidacy for EPG treatment based on the maturity and cognitive development of the child, regardless of chronological age. **Conclusion:** Dagenais concluded that children seven years and older are considered the best candidates for speech studies using EPG because of their higher vocabulary and
language test scores. Therapy using EPG for articulation disorders helped in some cases to focus individuals incorrect contact patterns to more specific regions on the palate in order to improve the precision of articulation, however, EPG did not help improve articulation disorders in all cases. Given these variable findings, using the EPG device for articulation disorders may need to be evaluated. EPG was useful however, with respect to phonological processing disorders for the purpose of detecting subphonemic contrasts for remediation.


**Objective:** Dean examined the effect that an EPG pseudopalate has on voiceless obstruents after 20 minutes of conversation. **Method:** Twenty adult speakers with typical speech participated in the study. Data were collected from each of the speakers during three speaking conditions: prior to placement of the pseudopalate, immediately following placement, and after 20 minutes of conversation. A spectral analysis was performed to examine all obstruent articulations. **Results:** Dean found that speaker’s obstruent productions were significantly disturbed upon placement of the pseudopalate. However, speakers were able to partially adapt their obstruent productions toward a more typical pattern of articulation following twenty minutes of conversation. **Conclusion:** Complete adaptation did not occur following 20 minutes of conversation while wearing the pseudopalate.


**Objective:** This study assessed linguapalatal contact patterns of /s/ and /t/ using EPG. **Methods:** Speech data was collected from five male subjects (three Arabic and two English), ranging in age from 19 to 21 years. The participants said words containing prevocalic /s/ and /t/ embedded in a carrier phrase. Each speaker was asked to say the phrases with and without a bite block in place. Recordings were taken immediately after insertion of the bite block and following 10-minutes of speech practice. **Results:** Speakers
often overcompensated for the presence of the bite block at both time intervals (after insertion and following 10-min practice). Significant differences in the length of constriction in /t/ were found as well as significant anterior-posterior tongue movement for /s/. English speakers were able to compensate more effectively to the bite block than the Arabic speakers. **Conclusion:** Speakers overcompensated in their speech articulation for /s/ and /t/ immediately following placement of the bite block and following 10 minutes of practice.


**Objective:** This study assessed whether bite blocks affect the latency and/or quality of vowel productions. **Methods:** Two different groups of participants were asked to produce a set of vowels (ʌ, u, a, ɛ, ɔ, i) with and without the bite block in place. One of the groups produced their vowels under time pressure while the other group did not. A reaction time using a sound spectrogram was used to analyze the group’s responses under time pressure. Vowel productions were evaluated based on the first and second vowel formants and a perceptual analysis. **Results:** The study found that vowels spoken with and without the bite block were produced with the same latency (the time between the visual presentation of the vowel and the speakers spoken initiation of that vowel). According to the acoustic and perceptual analysis, both groups of speakers (timed and untimed) produced vowels with similar quality and latency. **Conclusion:** A time constraint did not affect speaker’s ability to compensate to a bite-block.


**Objective:** This study analyzed the sex-related acoustic differences in adults and children when producing voiceless fricatives. **Method:** Both male and female adults and children (ages 6-14) were asked to participate in the study. Five age groups with ten males and ten females in each group produced words containing the voiceless fricatives (/f, θ, s, ʃ/) in a syllable initial CV context. The acoustic and spectral measures of fricative duration, amplitude, spectral peak, mean, variance, skewness, and kurtosis were measured.
Results: Very little evidence of differences between speakers in relation to their sex was found in the amplitude and duration fricative measurements. Younger children produced longer fricatives and vowels than both the older children and adults in the study. Spectral slope was higher in female speakers than males and the spectral mean declined for /ʃ/ in all speakers as age increased. Conclusion: Sex-related differences in the speech of younger children may be related to learned or behavioral factors.


Objective: This study took data on both the acoustic and articulatory differences in steady state vowels produced with and without a bite block. Method: Five adult males were used for this study. Each participant was asked to produce four Swedish vowels /i, a, u, o/. For the vowels /i/, /u/, and /o/ a 22.5-mm bite block was used, whereas the more open produced /a/ vowel was fixed with a 2.5-mm block. Each vowel was produced first without the bite block and then with the bite block in place. Acoustic data was collected and x-rays were taken during the study. Formant frequencies were also analyzed. Results: Only slight discrepancies existed between the pattern measurements taken suggesting that speakers were able to make compensations for the presence of a bite block. Analysis of the x-ray showed that speaker’s vocal tract shape with the bite block matched within 5 mm of the shape of the vocal tract without the bite block suggesting speakers were able to make some compensation to the bite block being in place. Conclusion: This study found that speakers were able to make compensations to the presence of a bite block through lip and tongue shapes.


Objective: This study examined speech therapists’ views on EPG as a method of treatment for articulation disorders. Methods: Ten therapists, who provided EPG therapy to a total of 75 individuals with speech disorders, completed a questionnaire. The questionnaire addressed the demographic age, type of speech disorder, details regarding
EPG therapy being used, and the therapist’s best judgment for outcome following therapy. *Results:* Almost half of the individuals receiving EPG therapy had a cleft palate, another third had functional speech disorders, and the remaining 23% of clients had mixed etiologies. The majority of the individuals receiving EPG therapy was male (62%) and had previously received more than five years of therapy (42%). The clients’ ages ranged from 3-70 years, with the majority being between the ages of 6-10 years old. Most frequently targeted sounds for therapy included /s/, /t/, /ʃ/, and /d/. Approximately 87% of EPG clients showed at least some improvement. However, of these individuals, the majority showed some generalization difficulties. *Conclusion:* Most individuals were able to improve their articulation with the use of EPG therapy; however, they often experienced difficulty generalizing skills learned in therapy to non-targeted sounds.


*Objective:* This study assessed how adults adapt the production and duration of the sibilants /s/ and /z/ when a dental prosthesis is placed in their mouth. *Method:* Sibilant duration was assessed on ten adult speakers while producing four phrases, three times each, under two different conditions: during natural speech with both a thin dental prosthesis and a thick dental prosthesis. Speakers were asked to wear a thin dental prosthesis while at home for two weeks. Data was collected while wearing the thick dental prosthesis before and after this two-week period. *Results:* Three of the individuals in the study showed complete adaptation. All others reported more natural speech following the two-week period wearing the prosthesis, however, they still experienced slight consonant distortions. Both /s/ and /z/ duration increased upon insertion of the thick prosthesis with the fricative /z/ showing the biggest duration increase. *Conclusion:* All participants showed some degree of compensation to the prosthesis, with even greater compensation occurring following the two weeks of wearing the thin dental prosthesis. Some adaptation occurred in a relatively short period of time.

**Objective:** This study attempted to evaluate the ability of young adults to adapt their speech to a dental prosthesis over a two-week period. **Method:** Thirteen young adult speakers with a reported history of /s/ articulation problems during childhood were selected for the study. Participants were required to wear a dental prosthesis during a two-week period in which speech was assessed before, during, and after this period. **Results:** Seven participants reported successful adaptation after the two-week adaptation period. The other six participants reported improvement but not complete adaptation. Of these six participants, some reported being physically conscious of the prosthesis in their mouth during the entire two weeks. Others employed strategies to aid in clearer speech such as slowing down their speech in an attempt to adjust to the prosthesis. Individuals who did not show adaptation showed groove narrowing, closer or unmoved jaw positioning, and tongue advancement. **Conclusion:** Speech adaptation was more difficult for speakers who reported history of childhood speech articulation disorders as opposed to those who were typical speakers and had no history of articulation deficits.


**Objective:** This study analyzed the spatial and temporal sequence of swallowing movements involving lip and tongue dysfunction. **Method:** Thirty-one subjects were observed during reflexive swallowing and while swallowing 20 ml of water. Individuals were divided into visceral and somatic swallowing groups and their swallowing movements were analyzed in further detail using spatial and temporal parameters. **Results:** Significant temporal differences were discovered in swallowing between the palate separation point and the end of swallowing. Significant differences were also found with the temporal measures used than with the spatial measures analyzed. **Conclusion:** Spatial analysis measures were the most reliable method to evaluate the effect that orofacial dysfunction has on swallowing.

**Objective:** This study examined which acoustic measures most accurately classify articulation placement for fricatives. **Method:** Ten males and ten females were selected to participate in this study. All participants repeated three CVC phrases containing a fricative /f, v, θ, s, z, ʃ,ʒ/ in the initial position of words, followed by a vowel /i, e, æ, a, o, u/, and the final consonant /p/. The elicited CVC target words started with the carrier phrase Say ______. Spectral, amplitudinal, and temporal measurements involving static and dynamic properties were analyzed for this study. **Results:** The acoustic measures of spectral peak location, spectral variance, spectral skewness, and relative amplitude measurements could be used to classify the fricatives place of articulation. **Conclusion:** Spectral moment analysis may be a valuable tool in discriminating between the fricative productions of adult speakers.


**Objective:** This study compared EPG-derived spatial and temporal measures between dysarthric individuals post traumatic brain injury (TBI) and typical individuals. **Method:** Speech data were collected from 11 dysarthric speakers post-severe TBI injury and 10 non-neurologically impaired individuals. Each speaker produced consonant-loaded sentences and syllable productions with the EPG pseudopalate in place. Speakers were given a desensitization period of at least one hour per day, starting one week prior to testing. A perceptual and acoustic analysis was used to evaluate the timing and spatial parameters of the contact patterns of the target sounds. **Results:** The temporal analysis revealed prolonged duration due to articulatory slowness, as well as impaired speech-motor control, accuracy, and coordination of articulatory movements by the dysarthric speakers. The spatial analysis revealed aberrations in tongue-to-palate contact of the dysarthric speakers. **Conclusion:** The researchers concluded that EPG could be used to describe the temporal and spatial tongue-to-palate contact patterns in the speech of dysarthric speakers following a severe TBI.

**Objective:** This study assessed how adults adapt their speech to the presence of an EPG practice pseudopalate. **Method:** Eight adults were recorded reading a series of words five times each under four different speaking conditions: (a) before pseudopalate insertion, (b) immediately after pseudopalate insertion, (c) 45-minutes after insertion, and (d) 3 hours after insertion of the device. The recorded words included the consonants /t/, /k/, /s/, or /ʃ/, followed by the vowels /i/, /a/, or /u/. The speakers’ adaptation was examined in terms of both acoustic and perceptual measures. **Results:** Despite perceptually mild consonant imprecision immediately following insertion of the pseudopalate, the results indicated that the adults were able to adapt their speech to the presence of the EPG palate after 45-minutes of practice. Results from the acoustic analysis showed no changes to vowel formant frequencies or segment durations. **Conclusion:** This study showed that adults were able to adapt their speech to an artificial pseudopalate within a 45-minute to 3 hour time period.


**Objective:** This study analyzed speech compensations made by speakers to the presence of a bite block. **Method:** Fifteen adult native French speakers were asked to participate in the study. Speakers produced a series of vowels, stops, and fricatives in isolation 10 times each. The speakers’ speech productions were recorded prior to placement of the bite block, immediately following placement of a large bite block, immediately following placement of a small bite block, and after 15-minutes of conversation with bite block in place. Adaptation to the bite block was evaluated using temporal and spectral measures. **Results:** Durational measurements for vowels and stop consonants were not significantly affected by the presence of the bite block. In addition, the first formant frequencies for the vowels were significantly higher in the large bite block condition than with the small bite block, whereas the second formant was higher for only the /u/ vowel tokens. Following 15-minutes of conversation, the analyses showed vowels to be unaffected, and centroid frequencies for stops and fricatives to be somewhat lowered. **Conclusion:**
Although speakers were able to adapt their vowels to the presence of the bite blocks after 15 minutes, some acoustic aspects of consonants continued to be affected.


*Objective:* This study evaluated speech adaptation to an EPG pseudopalate. *Method:* Three Australian English speaking adult females and four adult males were fitted with a thick and thin EPG pseudopalate. Speech recordings from the participants were collected over a period of two days at 16 points in time with and without the pseudopalate in place. At each of the 16 time intervals participants were asked to produce the phrases *a tea* and *a sea* ten times each, count from 1-20, and read *The Rainbow Passage*. The speech recordings were then analyzed acoustically and perceptually. *Results:* The acoustic analysis showed the spectral mean was significantly reduced following initial placement of the pseudo-EPG palate, which persisted through the production data collected a 45 minutes after placement of the device. However, these times did not differ from the no pseudopalate condition following one hour of wear. The perceptual analysis found speech was slightly distorted with the largest impact on speech during initial placement of the pseudopalate. *Conclusion:* The acoustic and perceptual findings indicated that the adult speakers’ speech productions were significantly impacted upon initial insertion of the EPG pseudopalate, however they were able to partially adapt to the device over time.


*Objective:* This study examined the acoustic and spectral characteristics of voiceless fricatives produced by children and adults. *Method:* Three groups of children (30 total) ages 3-6 years old and one group of adults (10 total) were selected to participate in the study. Participants repeated the carrier phrase *This is a ____* containing words with the voiceless fricatives /ʃ, θ, s,ʃ/ in the initial position, followed by a vowel /i, a, u/. These words were repeated five times each, yielding 60 tokens per speaker. Analyses assessing duration, amplitude, spectral slope, mean, variance, skewness and kurtosis were
performed. **Results:** The authors found that the duration, amplitude, spectral slope, and all spectral moments varied significantly with place of articulation. Spectral slope was important for the distinction and classification of fricatives. Spectral mean, skewness, and kurtosis analyses showed a widening of acoustic distinctions between the fricatives /s/ and /ʃ/ as age increased. **Conclusion:** This study showed that children’s fricative articulations, when compared to the adult articulations, continue to be fine-tuned as they grow older.


**Objective:** This study examined the acoustic and spectral characteristics of stop consonant productions produced by children and adults. **Method:** Three groups of children (30 total) ages 3-5 years old and one comparison group of adults (10 total) were selected for this study. Participants repeated the carrier phrase *This is a ___ again*, embedded with words containing a voiceless stop (/p, t, k/) in the initial position, followed by a vowel (/i, a, u/). The participant’s productions were examined in terms of duration, relative amplitude, spectral slope, mean, variance, skewness, and kurtosis.

**Results:** Findings indicated that all analyses performed, except spectral kurtosis, had significant variation across place of articulation. Spectral mean and skewness were able to differentiate alveolar and velar stops. Spectral variance could be used to distinguish /p/ from /t/ and /k/ across all ages. **Conclusion:** Although sex-related acoustic differences may be partially related to variations in vocal tract anatomy, this study suggests that differences may also be related to learned or behavioral factors.


**Objective:** This study tested the theory that children’s articulatory gestures are not as precise as adults and that some articulatory gestures are developed more quickly. **Method:** Participants for this study included 10 adults and 30 children from 3 to 7 years of age. Speech stimuli contained an initial consonant /s, ʃ, t, k/, followed by a corner
vowel /a, i, u/. Stimuli were elicited by pictures rather than by imitation. Spectral moment analyses were used to examine the acoustic nature of the target sounds. **Results:** The measure of spectral mean differed across fricative type depending on the age of the speaker, whereas the stop consonants did not show an age effect. **Conclusion:** These findings indicate that consonants develop to an adult-like form at differential rates.


**Objective:** This study examined the affect of a thin pseudopalate on the speech production of typically developing adults. **Method:** Speech recordings were collected from five male and six female adults between the ages of 28 and 48 years while speaking with and without an EPG pseudopalate. The speech stimuli included the syllables /tik/ and /sik/, embedded in the carrier phrase a____ again. The participants’ adaptation to the pseudopalate was evaluated through both acoustic and perceptual measures. **Results:** The study found that the consonants /t/ and /s/ were significantly effected immediately after placement of the pseudopalate. These changes were primarily observed acoustically rather than perceptually. Speakers were then able to adapt to the pseudopalate approximately 30 minutes following placement of the device in the mouth. **Conclusion:** Speakers are not able to adapt their speech immediately to the device, however, adaptation does occur within a short time period.


**Objective:** This study examined anticipatory coarticulation in one apraxic speaker using acoustic, perceptual, and EPG analyses. **Method:** One apraxic speaker and one typical speaker (as a control) participated in the study. Each participant produced six words containing the vowels /i, a, u/ embedded in the phrase Say ___ again at slow, habitual, and fast speaking rates. A perceptual analysis was performed in which listeners identified the vowel they heard from a set of six vowels. **Results:** Listeners had a harder time identifying vowels produced by the apraxic speaker. In all conditions, listeners identified
the /i/ vowel more often than the /u/ vowel. Initial consonants affected listener judgments of upcoming vowels and slower speaking rates yielded higher vowel identification rates. 

**Conclusion:** Apraxic speakers demonstrated delayed or distorted coarticulatory gestures across all speaking rates, but intelligibility decreased with faster speaking rates.


**Objective:** This study examined the effect that a small magnet placed on the tongue has on adult speech production. **Method:** Ten adult English speakers were selected to participate in the study. Participants were instructed to say the sentence *Allison had to miss a sunny vacation at Shellfish Bay* three times prior to placement of a lingual magnet, immediately following placement of the magnet, after five minutes of conversation, and again after another ten minutes of conversation. Speech recordings were collected with the magnet placed along the central sulcus at 10mm and 15mm from the tip of the tongue. The impact of the magnet on the fricative productions of /s/ and /ʃ/ and participants’ subsequent adaptation were examined through a series of acoustic and spectral parameters. **Results:** Spectral mean and variance values increased immediately following placement of the magnets for the fricative /ʃ/ in word final position, but not for the fricative /s/. Spectral means for the /ʃ/ and /s/ were higher in the 10mm placement than the 15mm placement. Speakers partially adapted their speech articulation to the presence of the magnet after only five-minutes of conversation. **Conclusion:** Fricatives were significantly affected by the presence of the magnet, however, adaptation occurred in a relatively short amount of time.


**Objective:** This study examined the effect of lingual pellets on speech production. **Method:** Twenty-one adult speakers between 18 and 36 years of age were recorded saying the phrase *She had your dark suit in greasy wash water all year.* The participants repeated the target sentence three times before placement of the lingual pellets and five
times after all 11 pellets were in place. Speech productions were evaluated through both acoustic (e.g., vowel formant frequencies, segment durations, formant trajectory, and spectral moments) and perceptual measures. **Results:** Acoustically the presence of the lingual pellets affected the nature of the speakers’ speech productions. However there was relatively little effect on the speech rate. Perceptually listeners could not consistently identify if the pellets were present during speech production. **Conclusion:** Although the acoustic analysis indicated that the pellets had an impact on the speakers’ articulation, the perceptual analysis revealed that listeners were unable to consistently determine when the pellet was present or not.


**Objective:** This study perceptually evaluated the effect that a pseudopalate has on adult speakers production of voiceless obstruent sounds. **Method:** Twenty adult listeners evaluated 20 adult speakers production of two different sentences, one sentence was stop-loaded (i.e., *the boot on top is packed to keep*) and one sentence was fricative-loaded (i.e., *the boy gave a shout at the sight of the cake*). Each speaker repeated both sentences five times over three different conditions: (a) prior to placement of an EPG pseudopalate, (b) immediately after placement of the pseudopalate, and (c) 20 minutes following placement. **Results:** According to the listeners’ ratings the articulatory quality of the speakers’ obstruent productions was significantly affected by the placement of the pseudopalate. Female speakers were rated as having better articulatory quality than male speakers, however, following the 20-minute adaptation period males were rated as having better articulatory quality than females. Stop-loaded sentences were rated as being more distorted than fricative-loaded sentences from the presence of the pseudopalate. Perceptually the speakers showed some adaptation following the 20-minute time period, but speech still remained distorted. **Conclusion:** The presence of a pseudopalate has a significant perceptual affect on a speaker’s articulation quality and varies based on a speaker’s gender and the type of obstruent being produced. The results also suggest that 20 minutes of adaptation might not be long enough for speakers to fully adapt their speech to the pseudopalate.
Appendix B
Informed Consent Documents

Parental Permission for a Child to be a Research Participant

Introduction
The purpose of this study will be to examine how younger speakers adapt their speech when a relatively thin palatal sensor is placed in their mouth. Your child is being invited to participate in this study because he/she is a native speaker of English with no history of speech, language, or hearing problems. This experiment is being conducted under the supervision of Shawn Nissen, Ph.D., an associate professor in the Department of Communication Disorders at Brigham Young University.

Procedures
Initially, your child will participate in a hearing screening, you will give a summary of the results of this screening. If your child’s hearing is typical, your child will be fitted with a custom made palatal sensor (similar to an orthodontic retainer). The sensor is approximately 2 mm thick and conforms to the upper teeth and palate. You will be asked to have a dental impression created by a licensed dental professional, the cost of which will be prepaid for you. A list of possible dental professionals will be provided, but you are welcome to have an impression created by another dentist or technician of your choice. After the sensor is made your child will be asked to wear the sensor during one three-hour period of time. During this period of time they will be asked to interact in play and conversation with other children their age and have their speech audio recorded while reading a series of age-appropriate words and sentences, as well as several minutes of conversation. At a later date, these audio recordings will be analyzed and rated by adult listeners for intelligibility.

Risks/Discomforts
There are minimal risks associated with participation in this study. The palatal sensor is similar to an orthodontic retainer and may cause some minor discomfort to the gums or teeth during use. The participant may encounter some minor discomfort when the dental impression (which is used to create the sensor) is being created. The finished sensor is too large to be accidentally swallowed; in addition it is attached to the data collection unit. Your child’s speech may sound different with the sensor in place and it may take a period of time for them to become accustomed to speaking with the sensor in their mouth. Your child may encounter some social discomfort in talking to peers while wearing the sensor, which will be minimized by talking to group about the study beforehand and the fact that all children in the group will also be wearing a similar device.

Benefits
There are no direct or guaranteed benefits for participants of this study.

Confidentiality
The audio recordings and all information provided will remain confidential and will only be reported as group data with no identifying information. All data, including digital recordings of your child’s responses will be kept on a password protected computer in a locked laboratory and only those directly involved with the research will have access to them.

Compensation
Your child will be compensated $10 an hour for their participation.

Participation
Participation in this research study is voluntary. Your child has the right to refuse to participate or withdraw at any time without penalty.

Questions about the Research
If you have questions about this study, contact Shawn Nissen, Ph.D., at (801) 422-5056 or shawn_nissen@byu.edu.

Questions about your Rights as Research Participants
If you have questions regarding your rights as a research participant, you may contact the BYU IRB Administrator, A-285 ASB, Brigham Young University, Provo, UT, 84602 or at (801) 422-1461.

I have read and fully understand the consent form. Any questions have been answered to my satisfaction. I give permission for my child to participate in this research.

Signed: ___________________________
(signature of participant’s parent or legal guardian)

Date: ________________

Child’s Name: ___________________________

Institutional Review Board

05/02/13 05/02/14
Approved Expires
Child Assent to be a Research Participant

We want to tell you about a research study we are doing. This study is meant to find out more about how best to help kids with their speech. You are being asked to join the study because you speak English and your speech is similar to other kids your age.

If you decide that you want to be in this study, this is what will happen.
- We will check your hearing by having you listen to some beeps in headphones.
- A person will make a mold of your teeth by having you bite into a tray filled with a material that fits around your teeth. The mold takes about 10 minutes to make. This material is a little sticky, but it can be removed by brushing your teeth after it is made. From this mold we will make a thin piece of plastic, called a sensor, that fits over your teeth like a retainer.
- You will then come to a building at BYU with your parents one time for 3 hours. During this time you will play and talk with 4 other kids your age and a speech teacher while wearing the sensor in your mouth like a retainer. All of the kids in the group will also be wearing the same sensor that you will be wearing.
- Four times while you are playing someone will record your voice with a microphone. We will not play this recording to anyone you know and we will not put your name on it. Then a small group of adults will listen to the recordings after you have left.
- You will receive $10 for each hour you participate in the study.

Do I have other choices?

You can choose not to be in this study. It’s up to you. If you say yes now, but you change your mind later, that’s okay too. All you have to do is tell us.

Will anyone know I am in the study?

We won’t tell anyone you took part in this study. When we are done with the study, we will write a report about what we found out. We won’t use your name in the report.

Before you agree to be in this study, be sure to ask the person helping with the study to tell you more about anything that you don’t understand.

If you want to be in this study, please sign or print your name.

☐ Yes, I will be in this study. ☐ No, I don’t want to do this.

Child’s name ____________________ Signature of the child ____________________ Date __________

Person obtaining Assent ____________________ Signature ____________________ Date __________

Institutional Review Board

BYU

05/02/13 05/02/14

Approved Expires